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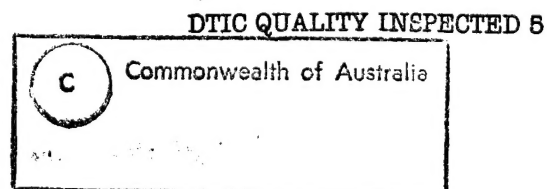
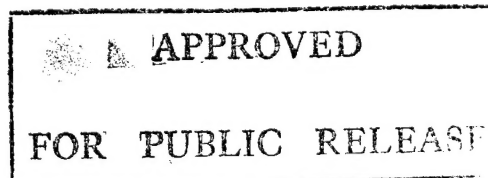
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Water Model Tests on the Allison T56
Series III Combustion System

G.T. McCabe



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**Airframes and Engines Division
Aeronautical and Maritime Research Laboratory**

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ABSTRACT

A modification was developed for the combustion system of the Allison T56 Series III turboprop engine which has resulted in an engine that has:

- a lower smoke emission;
- a lower specific fuel consumption; and
- a combustor with potentially increased durability or life.

In-service testing of the combustor has proven all the above advantages; however, the formation of hard carbon in the combustor and its subsequent release has resulted in increased erosion in the turbine section of the engine. Further development was undertaken to remedy this problem without affecting the overall gains offered by the modification. This report covers part of this work and, in particular, details flow field investigations made using a water flow model of the combustor liner. A comprehensive understanding of the flow mechanisms within the standard liner, the Low Smoke Modification liner (LSM), and proposed revisions of the LSM liner has now been obtained. It is anticipated that modifications arising from the present investigation will reduce, if not completely eliminate, hard carbon formation in the Revised LSM (RLSM) form.

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Published by

*DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne Victoria 3001 Australia*

Telephone: (03) 9626 7000

Fax: (03) 9626 7999

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AR No. 007-138

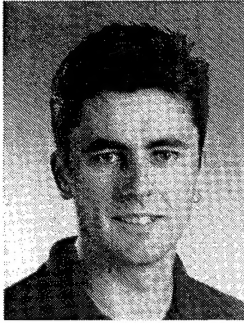
MARCH 1995

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Grant McCabe graduated from the Royal Melbourne Institute of Technology in 1991, having obtained a Bachelor degree in Aerospace Engineering with honours. He commenced employment at the then Aeronautical Research Laboratory (ARL) Salisbury as a cadet engineer in 1990 before joining ARL Melbourne as a graduate engineer in 1991. Grant has worked in several areas, including aircraft flight dynamics, cockpit display simulation, aerothermodynamics and combustion, airframe finite element analysis, helicopter flight dynamics and performance, and air combat modelling. He is currently involved with aircraft infra-red signature determination.

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1. Introduction

The Royal Australian Air Force (RAAF) currently operates the Hercules C-130E and C-130H transport aircraft and the Orion P-3C maritime reconnaissance aircraft. These aircraft are each powered by four Allison T56 turboprop engines which have serious emission problems including high levels of visible smoke. This characteristic is undesirable tactically as well as environmentally, and a RAAF-sponsored task was undertaken to investigate methods to reduce the emission levels from T56 engines. Modifications were developed which significantly reduced these emissions (Skidmore, Reference 2); however, after an in-service trial of a number of modified engines, the RAAF discovered excessive erosion in the turbine section of some of the engines. The erosion, evidently caused by hard carbon produced in the combustors, was principally located in a band just downstream of the guide vanes and on the leading edge of the first stage turbine rotor blades. The work contained in this report is part of the effort to determine a solution to the erosion problem.

2. Background

In the Allison T56 turboprop engine, a 14-stage axial flow compressor delivers air to a can-annular combustion system containing six combustor liners. These liners direct hot gases into a four-stage axial flow turbine. The turbine drives the compressor and propeller (and reduction gear box) through a single shaft.

The combustion system is the focus of this investigation, as it was believed that this section was the source of the erosion-causing particles being produced by the engine. Each combustor liner may be divided into three main sections (see Figure 1):

- the Primary Section, where the fuel/air mixture is ignited and combustion sustained;
- the Secondary Section, where combustion is completed; and
- the Tertiary Section, where combustion products are diluted and 'cooled' before entering the turbine.

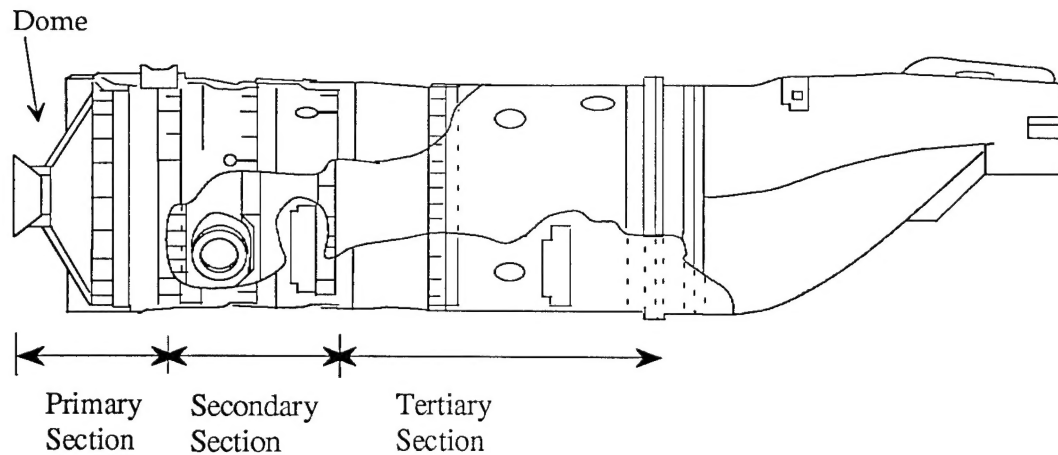


Figure 1 : Allison T56 Series III Combustor Liner

Approximately 65% of the air passing through the combustion section enters the combustor liners through circular air entry holes; the remainder is cooling air which enters through corrugations which encircle the liner at five different longitudinal locations. Small air entry holes exist in the dome, and larger holes are positioned around the liner at the primary, secondary, and tertiary sections.

2.1. Low Smoke Modification

The RAAF operates three variants of the T56 engine:

- T56-A-7 Series II (Hercules C-130E aircraft);
- T56-A-15 Series III (Hercules C-130H aircraft); and
- T56 -A-14 Series III (Orion P-3C aircraft).

The Series II engines are known to produce far less visible smoke than the Series III engines (Skidmore, Reference 1). The design changes which distinguish the Series III engine from the Series II engine include modifications to the combustion section. The modified combustion section incorporates a larger combustor outlet area and a different air inlet distribution through the combustor liners. The major airflow variations occur in the primary section where flow through the dome air inlet holes is increased from 5.4% to 8.1% of the total flow and flow through the primary section holes is decreased from 6.4% to 3.4% of the total flow. Rosfjord (Reference 3) states that soot (smoke) formation is sensitive to variations in primary section flow characteristics, as does Pearce (Reference 4). Therefore, it could be argued that the change in airflow through the primary section of the liner is a major contributor to, if

not the sole reason for, the increase in smoke emissions from the Series II to the Series III engines.

From the point of view of smoke emission, Skidmore (Reference 2) argued that the major problem area in the Series III liner was the poor mixing and flow structure in the dome area and primary section of the liner. It was concluded that the major deficiencies were:

- The air entering through each of the inlet holes around the primary section (the primary holes) should form a jet that penetrates to the centre-line of the liner while staying in line with the primary holes (this would help mixing and recirculation).
- The recirculation pattern should be stronger which again would help mixing and aid flame stabilisation.
- There should be no secondary region of recirculation in the vicinity of the fuel atomiser, since this could promote carbon build-up by reintroducing burning fuel drops into a region where they could impinge on a cold surface.

The flow field in the standard Series III combustor liner as reported by Skidmore (Reference 2) is shown schematically in Figure 2.

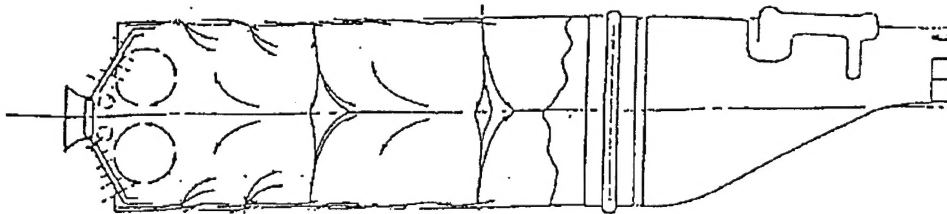


Figure 2 : Flow Field in the Standard Combustor Liner

A modification was developed in order to address the deficiencies described above. The modification was based on increasing the quantity of air being supplied to the primary zone of the liner. This increase was achieved by enlargement and reshaping of the primary air inlet holes, as well as minor relocation (see Figure 3). It is to be noted that the AMRL Low Smoke Modification (LSM) to the Allison T56 Turboprop Engine is covered by US Patent No. 5,138,841 on Gas Turbine Engines.

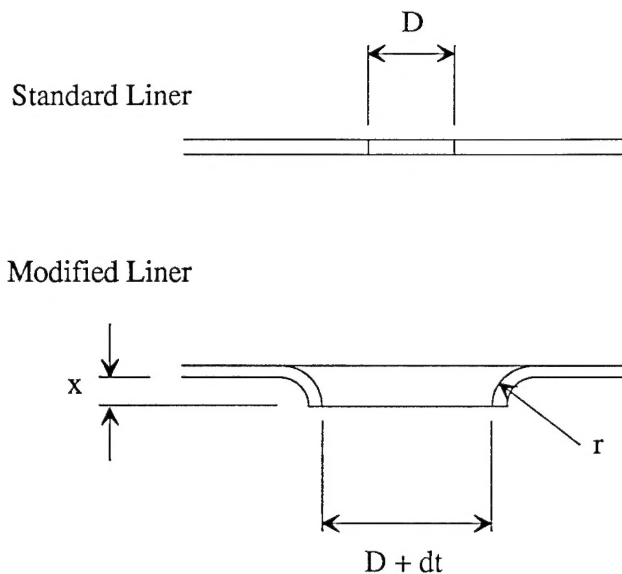


Figure 3 : Comparison between the Standard and Modified Primary Section Holes

Figures 2 and 4 provide a comparison between the flow inside a combustor liner of the standard and the LSM configurations respectively. The main vortex in the primary section of both liners is toroidal, as is the smaller secondary vortex shown in Figure 2. Skidmore (Reference 2) noted that the flow inside the LSM liner had a much stronger main toroid, and displayed no sign of any secondary toroid. The other main feature of the flow in the LSM liner was the much stronger penetration of the flow through the primary holes.

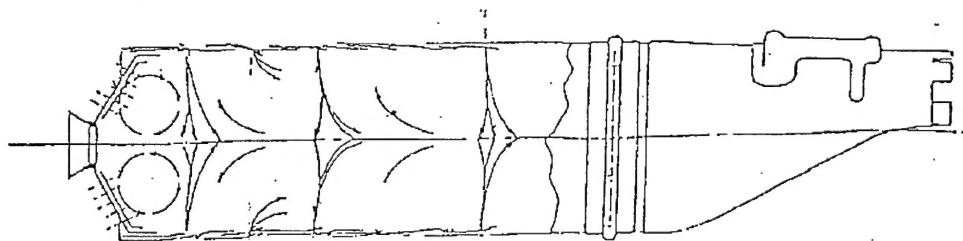


Figure 4 : Flow Field in the Combustor Liner Modified for Smoke Reduction

The changes to the flow within the primary section of the LSM liner were beneficial in terms of smoke reduction, but in achieving this, an imbalance in the dome to primary section air ratio could have occurred. An imbalance of this nature might have led to the carbon build-up inside the LSM liner. The principal concern was with the main toroid in the primary section of the LSM. Given that the strength of the toroid had increased, it was possible that its size had also increased, or its position had moved longitudinally either towards or away from the dome of the liner, or a combination of both had occurred. Other areas of concern were possible regions of stagnation, or areas of poor mixing in the dome region causing local pockets of high fuel to air ratio, resulting in the formation of hard carbon. It is generally understood that hard carbon tends to be formed where locally hot, fuel-rich, and relatively stagnant conditions occur adjacent to a surface (Tomlinson and Montgomery, Reference 5).

Using a water flow model of the combustor liner, an investigation was initiated to re-examine the flow within both the standard liner and the LSM liner with the aim of assessing changes in the flow which may have caused or at least contributed to carbon formation.

3. Flow Model Set Up

The water flow model used in this investigation was essentially the same as that used by Skidmore (Reference 2). It consisted of a perspex enclosure representative of a 60 degree sector of the T56 combustion system, and included a replica of the compressor outlet to combustor inlet section used in the actual engine. The combustor liner placed inside this sector (see Figure 5) had viewing windows cut into it which were covered with perspex. Small holes along the length of the 60 degree sector allowed dye to be injected into the liner using a hypodermic syringe. A mixture of titanium dioxide powder in water was used in preference to dyes because the white particles, which displayed approximately neutral buoyancy, were less susceptible to being quickly dispersed. The water was delivered to the system from storage tanks by electrically driven pumps, and the rate of flow was measured using an orifice plate flow meter. In contrast to Skidmore's original investigation (Reference 2), the rig was modified to provide for the insertion of a small video camera along the axis of the combustor liner. Pictures from this camera would allow flow fields to be observed at right angles to those previously investigated; that is, from an axial perspective. This would also enable non-axisymmetric flows to be observed, which may be attributed to the shape of the compressor outlet to combustor inlet section through which the water flows before entering the liner.

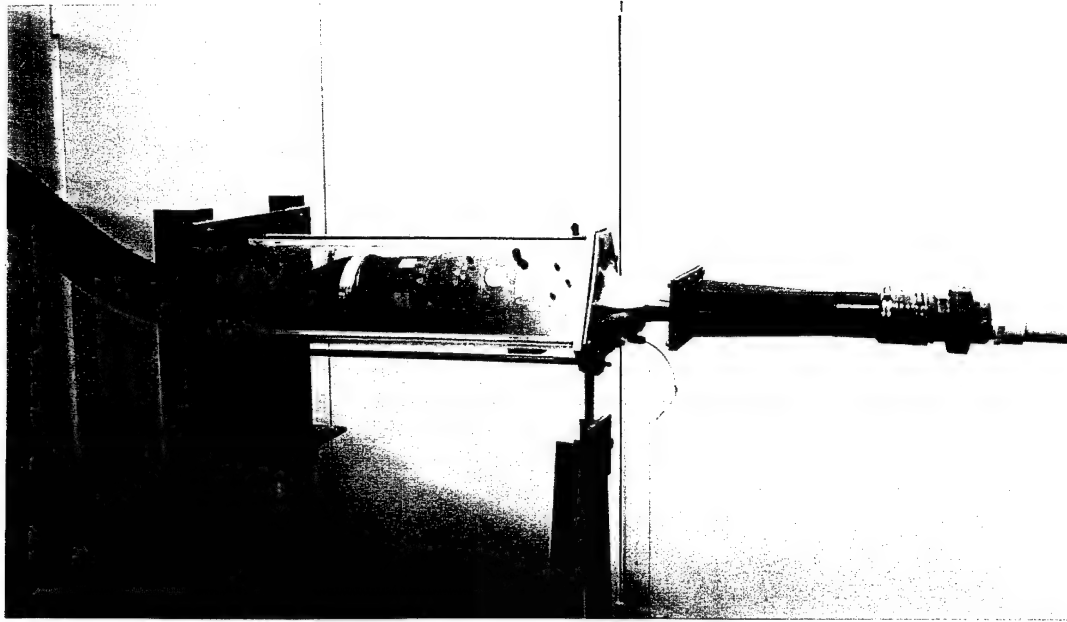


Figure 5 : Water Flow Model

The Reynolds number based on the height of the diffuser inlet in actual engine operations is approximately 500000. The Reynolds number used in the water flow tests varied between 200000 and 300000 depending upon flow rates used. While this is lower than the actual engine operating value, the difference is of little practical significance because, with Reynolds numbers of this magnitude, the observed large scale flow field inside the flow model would be closely representative of the actual flow field.

4. Primary Section Flow Field

The first phase of this investigation was to repeat Skidmore's (Reference 2) work in studying the flow field within the primary section of standard and LSM versions of the combustor liner. This would permit confirmation of Skidmore's findings, and would allow, using the miniature camera, a much closer examination of the subtleties of the flow field which could shed some light on the cause of the carbon formation.

4.1. The Standard Configuration

The flow field within the primary section of the standard liner was found to be quite weak, although the basic features were visible. The penetration of the flow through the primary holes into the liner was minimal, as shown in Figure 6.

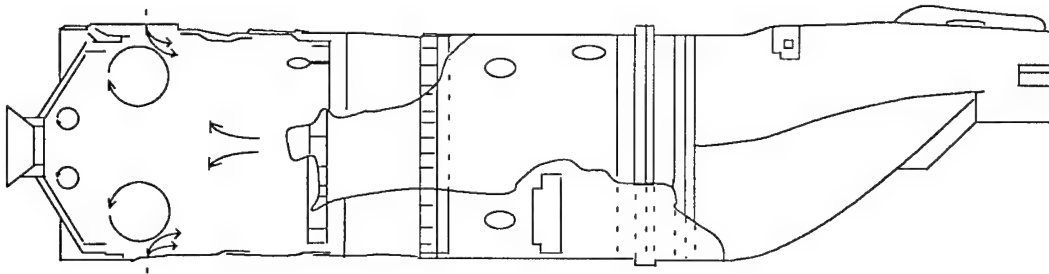


Figure 6 : Flow Field within the Primary Section of the Standard Series III Combustor Liner

The main toroid was visible, although at times it was difficult to detect due to its lack of energy. A secondary toroid located close to the fuel atomiser was also detected, as was a region of recirculation downstream of the main toroid. The secondary toroid appeared to be stronger than the main toroid but was significantly smaller. The characteristics of the main toroid were difficult to establish because of the relatively weak flow, but close examination of the swirling titanium dioxide particles did reveal the approximate size and longitudinal position of the main toroid.

Using the inside of the liner as a reference (see Figure 7), titanium dioxide particles were observed to be swept into the flow of the main toroid as far upstream as the beginning of section 'c'. Similarly, the downstream end of the toroid structure appeared to terminate just before the end of section 'c'. The core of the vortex was centred at approximately the centre-line position of the primary holes.

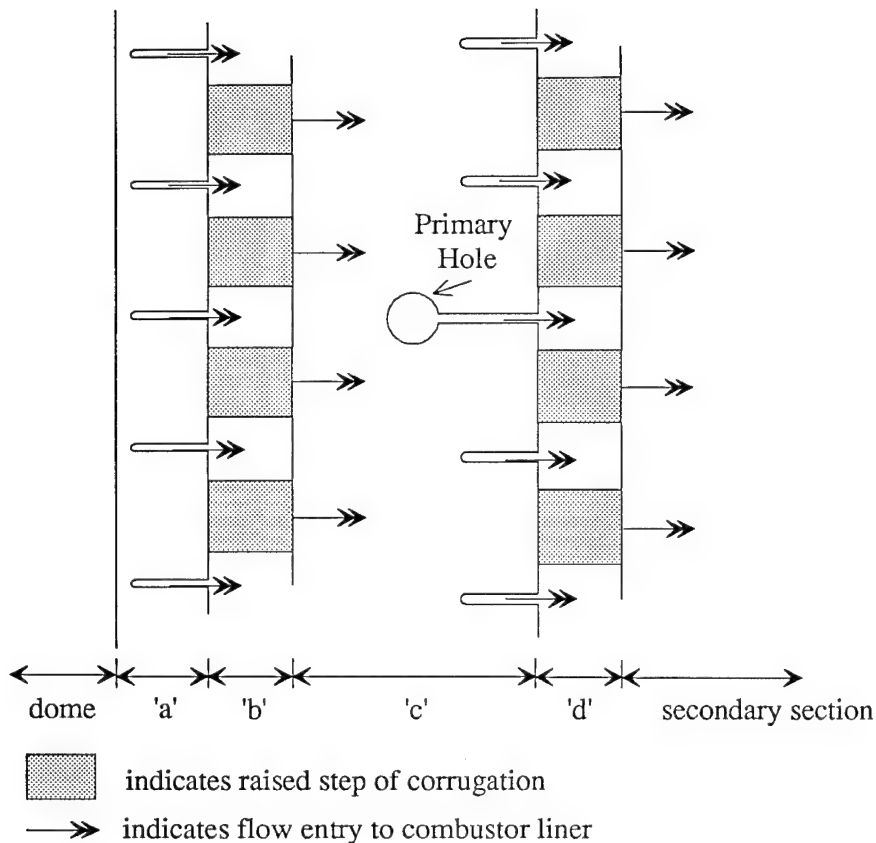


Figure 7 : View inside the Skin of the Primary Section of the Combustor Liner

4.2. The Low Smoke Configuration (LSM)

The flow field inside the primary section of the LSM liner was relatively easy to trace as the main features of the flow were significantly stronger than those of the standard liner. The flow through the primary holes was the strongest feature observed in the primary section, penetrating through to the centre-line of the liner as shown in Figure 8. The main toroid was quite vigorous, and it was clear that its location had moved upstream as a consequence of the LSM. The toroid influenced titanium dioxide particles close to the upstream end of section 'a', but it could not be determined whether its structure was impinging on the inside of the dome. The downstream limit of the toroid appeared to extend to the primary section holes. These bounds indicate that the main toroid had not only shifted its position upstream as a consequence of the smoke reduction modifications, but it had also increased in size by between 30 and 40 percent. There was no evidence of a secondary toroid in the vicinity of the atomiser.

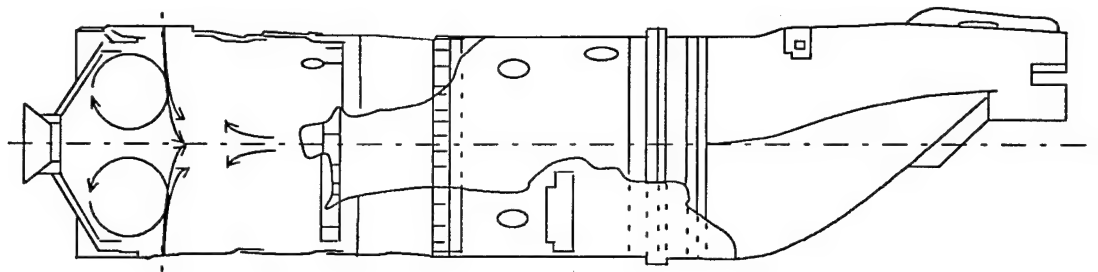


Figure 8 : Flow Field within the Primary Section of the LSM Series III Combustor Liner

4.3. Influence Of Flow Entering Via The Dummy Igniter

The combustion system has two igniters which are installed in two of the six combustor liners (see Figure 9). Longitudinally the igniters are positioned in line with the primary holes of the liner. The other four liners have 'dummy' igniters installed, which are configured to admit approximately the same amount of air as the cooling flow through an actual igniter. The diameter of the air entry hole in the dummy igniter is approximately the same as the diameter of the primary holes of the unmodified liner. The original water tunnel model (Reference 2) had this fluid entry point blocked, and consequently any possible influence on the flow pattern was ignored. To assess its effect, a dummy igniter was manufactured and installed in a LSM liner and the effect of flow through it investigated.

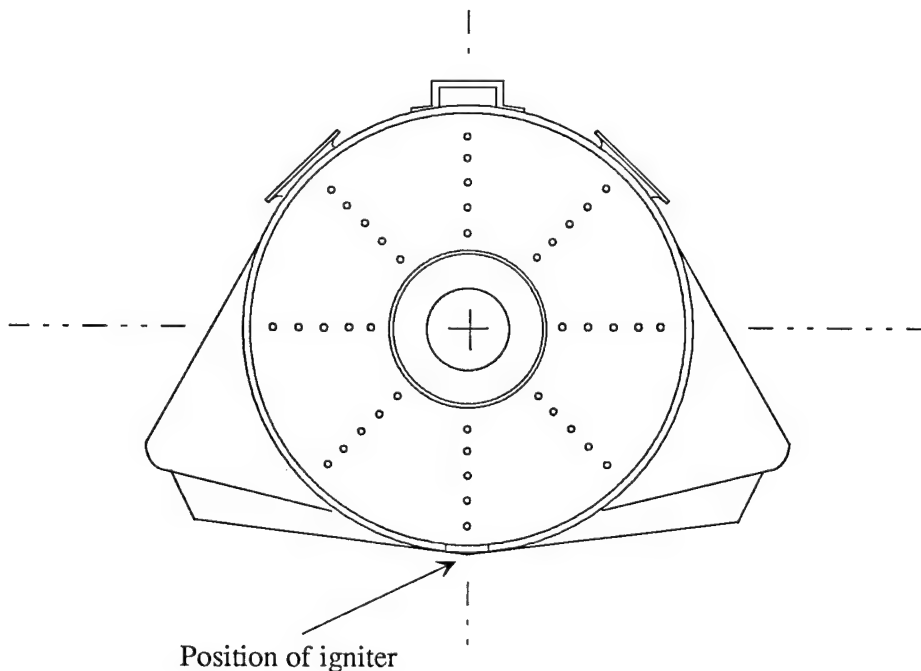


Figure 9 : End View of a Combustor Liner Showing Position of Dummy Igniter

Close inspection of the flow field revealed that there was a noticeable influence on the flow in the region of the igniter, albeit relatively minor in the total scheme. The penetration of the flow through the dummy igniter was weak when compared with that entering through the other primary section holes, and was probably comparable to the penetration displayed by the primary holes of the standard liner.

It is reasonable to postulate that in the LSM liner, the toroid has a relative weak spot in the region around the dummy igniter since the flow through this orifice is much weaker than the flow through the other primary section (enlarged) holes. This may not be the case with the standard liner as the strength of flow through the igniter is approximately the same as that through the other primary section holes.

5. Flow Field Entering Via Swirl Vanes

The water flow model tests on the standard and LSM liners were undertaken simultaneously with an experimental test program on a T56 liner in a 'hot' rig equipped with a particle separator to catch the hard carbon produced in the liner. The 'hot' rig was used to determine the tendency of the liners (standard and LSM) to generate hard carbon and to assess empirically any revisions developed in the water flow modelling.

During the 'hot' tests it was discovered that hard carbon was forming on the swirl vanes located on the inside of the dome. Figure 10 shows the swirl vanes viewed from inside the combustor liner, looking towards the dome.

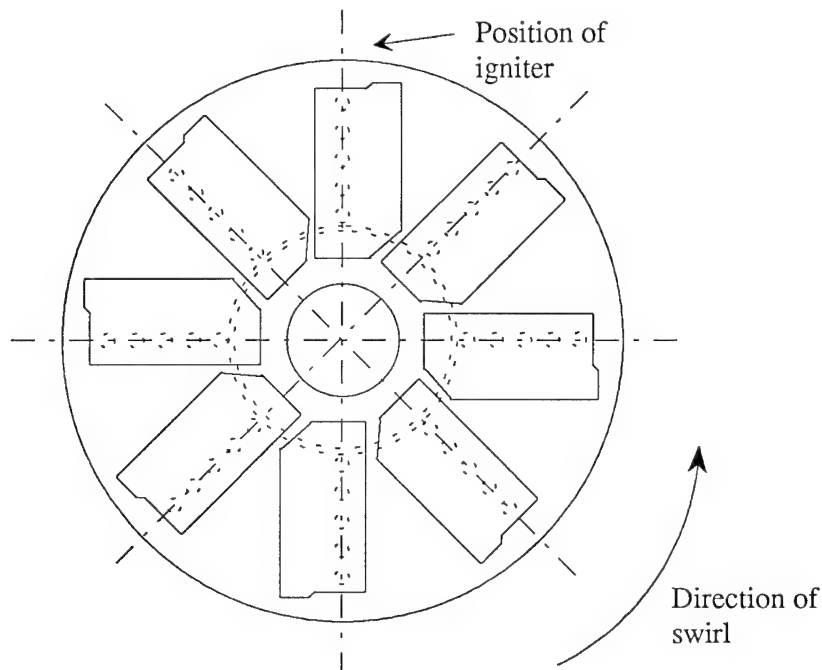


Figure 10 : View of the Swirl Vanes inside the Dome

Prior to the present series of water modelling experiments, tests using the 'hot' combustor rig with particle separator installed found that carbon formation was strongly dependent upon the size and location of the holes in the dome of the liner prior to the swirl vanes. A number of changes to individual hole diameters had been assessed, but there remained a tendency for hard carbon to deposit on the (swirl) vane at the 'half past one' position at the corner closest to the outside of the liner; that is, nearest to the 12 o'clock position (see Figure 10). The carbon was forming within a sharply defined boundary, indicating that there was an area over which fluid was not consistently flowing. The immediate purpose of the water flow experiments was to investigate the flow in this region of this vane, map its flow properties and then develop a revision to prevent the hard carbon forming.

This area of the dome is very difficult to observe from outside the liner, and even more difficult to light for video or photographic recording. This difficulty was overcome by using a 'lipstick' style Charge Coupled Device (CCD) camera which was located inside the liner within a waterproof case. Three small six volt globes were inserted inside the liner at the downstream end of the primary section to provide lighting. Titanium dioxide and water mixture was carefully injected into the dome air entry holes behind each vane, and the flow field recorded. This technique made it possible to identify the holes through which fluid affecting the area in question was flowing, and allowed modifications to be developed.

The vanes are attached to the dome along one edge only so the fluid enters the liner in an anti-clockwise direction viewed from downstream (see Figure 10). Particular care was taken to record the behaviour and origin of the flow which passed over the vane on which hard carbon was known to form; in particular, the flow delivered by the row of holes behind the three o'clock vane.

5.1. Relevant Geometry

As noted above, concurrent 'hot' tests had indicated that the amount of hard carbon produced inside the combustor liner was sensitive to changes in size to the air entry holes located behind the swirl vanes. Table 1 gives the sizes of these holes for the standard T56 Series II and Series III combustor liners as used by the RAAF; these are the same as those on the LSM liner (Reference 2). The position of each hole is referenced by the following:

- A circumferential station, which references the vanes shown in Figure 10 to a clock face.
- A number from one to five, one being the hole at the extreme outside radius and five being the hole closest to the centre of the liner.

At the time of the current investigations, one particular liner modification, LSMR1, appeared to significantly reduce the amount of hard carbon formed inside the liner. LSMR1 involved changes in size to dome air inlet holes as follows:

- Hole #1 at the six o'clock position - size increased from 0.172 inches to 0.202 inches.
- Hole #2 at the six o'clock position - size increased from 0.125 inches to 0.172 inches.
- Hole #2 at the half past four position - size increased from 0.125 inches to 0.172 inches.

The flow field over the vanes was observed for the LSM liner, and then again for the LSMR1 liner. Notwithstanding the reduction in carbon achieved with LSMR1, there was no noticeable change in the flow pattern in the region of interest between the LSM liner and the LSMR1 liner.

Table 1 : Geometry of Dome Air Inlet Holes for the Series II And Series III T56 Engines

Circumferential Station	Hole Diameter (inches)				
	Hole #1	Hole #2	Hole #3	Hole #4	Hole #5
12 o'clock	0.202	0.172	0.125	0.125	0.125
Half past one	0.202	0.172	0.125	0.125	0.125
Three o'clock	0.202	0.172	0.125	0.125	0.125
Half past four	0.202	0.125	0.125	0.125	0.125
Six o'clock	0.172	0.125	0.125	0.125	0.125
Half past seven	0.172	0.125	0.125	0.125	0.125
Nine o'clock	0.172	0.125	0.125	0.125	0.125
Half past 10	0.202	0.125	0.125	0.125	0.125

5.2. Flow Field With Standard Size Dome Air Inlet Holes

The aim of this aspect of the investigation was to find out which hole or holes might influence the flow in the region associated with the carbon build up on the vane at the half past one position. Using a Series III-LSMR1 combustor liner, a titanium dioxide powder and water mixture was injected at the air inlet holes behind the vanes at the three o'clock and half past one positions. Results of these tests are given in Sections 5.2.1 and 5.2.2 respectively.

5.2.1. Flow From Behind The Three O'Clock Vane

- Figure 11 depicts the spread of the titanium dioxide particles injected at hole #1 at the three o'clock vane. At no stage did this flow sweep over the region of interest.

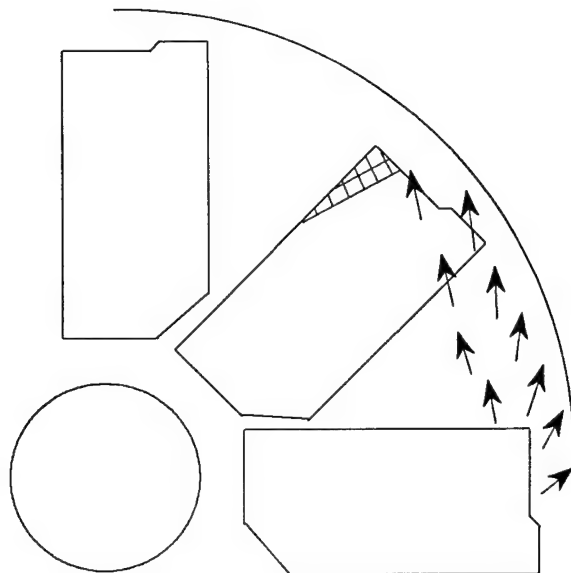


Figure 11 : Flow from Hole #1, at the Three O'Clock Vane

- The titanium dioxide particles injected at the hole #2 at the three o'clock vane were dispersed as shown in Figure 12. The 'critical region' on the half past one vane appeared to be swept completely by this flow, although it was not immediately clear if the flow contacted the vane or whether it was swept downstream before passing over the vane. However, close examination of video evidence did reveal titanium dioxide particles clinging to parts of the 'critical region' on the half past one vane, indicating that the flow did on occasions contact its surface. It was not possible to establish if the flow passed over the entire region of the vane where hard carbon was observed to be building up.
- Particles entering through hole #3 at the three o'clock vane were dispersed as shown in Figure 13. The particles did not appear to pass over the corner of the half past one vane where hard carbon was known to form. However, video analysis did reveal that the flow intermittently crossed this area. As with hole #2, the titanium dioxide particles clung to some areas of the vane at the half past one position, indicating that some fluid was contacting the surface.

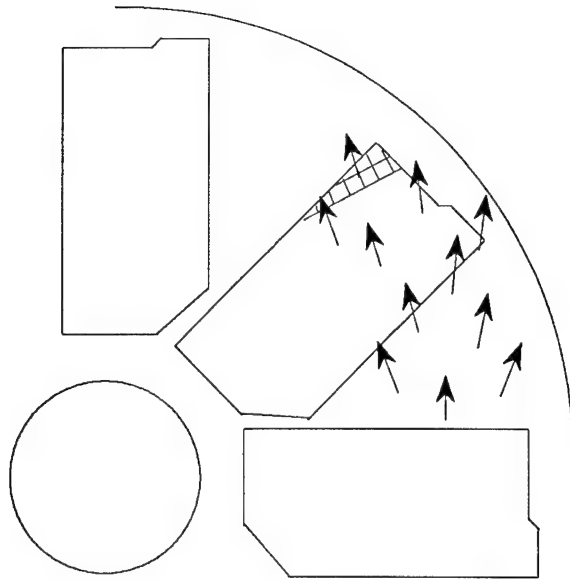


Figure 12 : Flow from Hole #2 at the Three O'Clock Vane

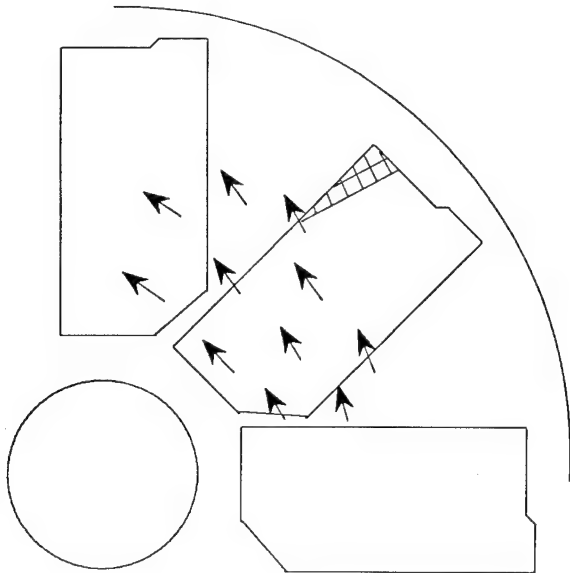


Figure 13 : Flow from Hole #3 at the Three O'Clock Vane

- The titanium dioxide particles injected at the remaining two holes at the three o'clock vane did not appear to sweep near the 'critical region' on the half past one vane where hard carbon was known to be forming. The respective flow mappings are shown below in Figures 14 and 15.

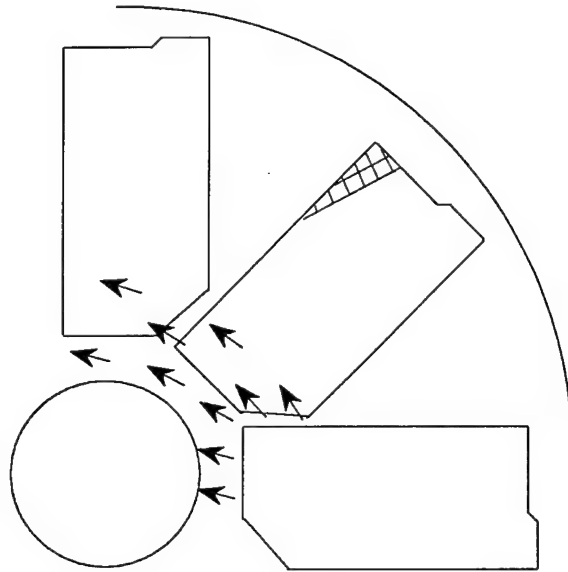


Figure 14 : Flow from Hole #4 at the Three O'Clock Vane

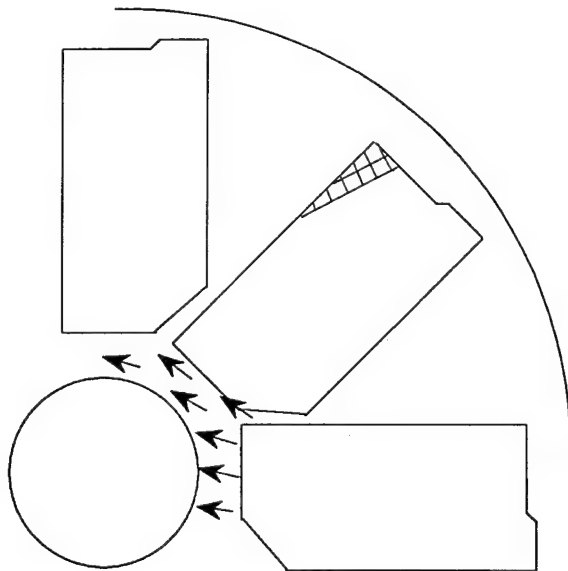


Figure 15 : Flow from Hole #5 at the Three O'Clock Vane

5.2.2. Flow From Behind The Half Past One Vane

In assessing the flow over the top corner region of the half past one vane, the fluid entering the liner from holes behind this vane was investigated. The holes of particular interest are holes #1 and #2.

- The distribution of particles injected at hole #1 is shown in Figure 16. Video recordings of this flow revealed a characteristic unique to this vane, in that the particles entered the liner almost entirely under the side (end) of the vane closest to the wall of the liner. Close investigation of video recordings showed that some recirculation was evident, and flow was seen to impinge on the corner of the vane where hard carbon was forming.
- Figure 17 shows the distribution of particles injected at hole #2 at the half past one vane. The particles were observed to enter the liner under the side (end) of the vane and under the front, with the majority entering under the front. It was apparent that none of the particles swept the upper surface of the vane.

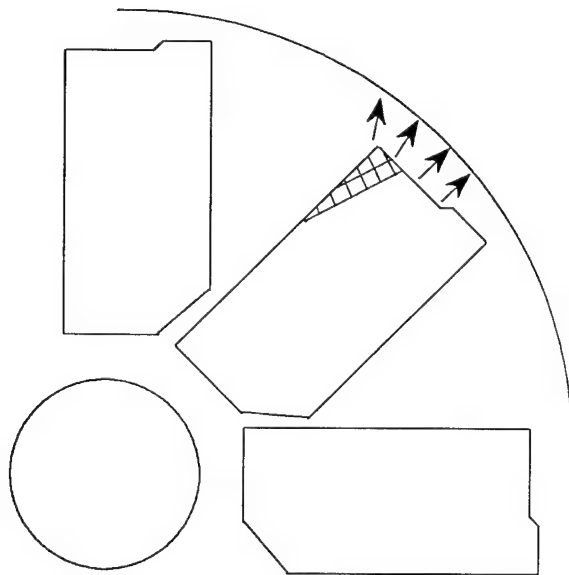


Figure 16 : Flow from Hole #1 at the Half Past One Vane

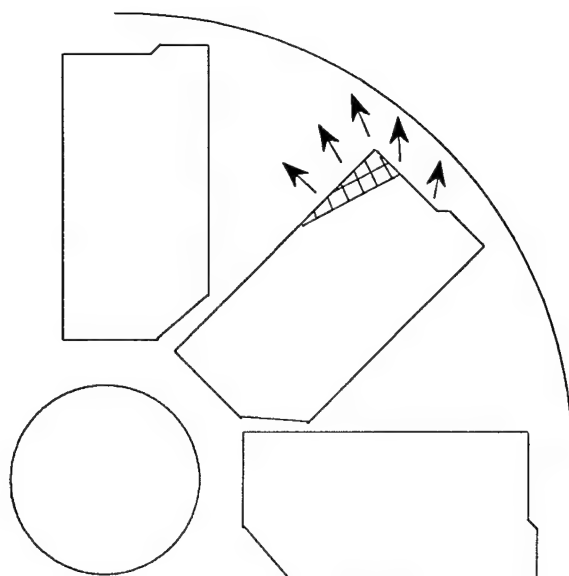


Figure 17 : Flow from Hole #2 at the Half Past One Vane

- Titanium dioxide particles were injected at holes #3 to #5, but there was no evidence of the region of interest being affected.

5.3. Revision Four

As a result of the investigation described in Section 5.2, it was apparent that the quantity of flow passing over the area where hard carbon was building up on the half past one vane might be increased by enlarging hole #2 behind the three o'clock vane. This modification, designated Low Smoke Modification Revision Four (LSMR4), following on from a revision series initiated earlier in the investigations, is distinguished from the standard Series III configuration as follows:

- Modifications as previously detailed which produce LSMR1.
- Hole #2 at the three o'clock position - size increased from 0.172 inches to 0.202 inches.

Note that the above hole reference is consistent with the convention for Table 1.

This modification appeared to strengthen the flow over the region upon which hard carbon was known to be forming. The region swept by titanium dioxide particles injected at hole #2 appeared to be slightly larger than with the standard size hole, and the orientation of the flow was altered slightly such that it was directed less towards the wall of the liner (see Figure 18). Investigation of the video recordings revealed that the titanium dioxide particles clung to the vane over the entire region through which it swept, in contrast to the patchy and inconsistent manner evident with the LSMR1 liner. The effect of this revision on the flow through hole #3 at the three o'clock vane demonstrated no obvious change in the flow structure from that shown for the LSMR1 liner.

The only other flow mapping undertaken for LSMR4 was with titanium dioxide particles injected at hole #1 at the half past one vane. No changes in the distribution of the particles was detected.

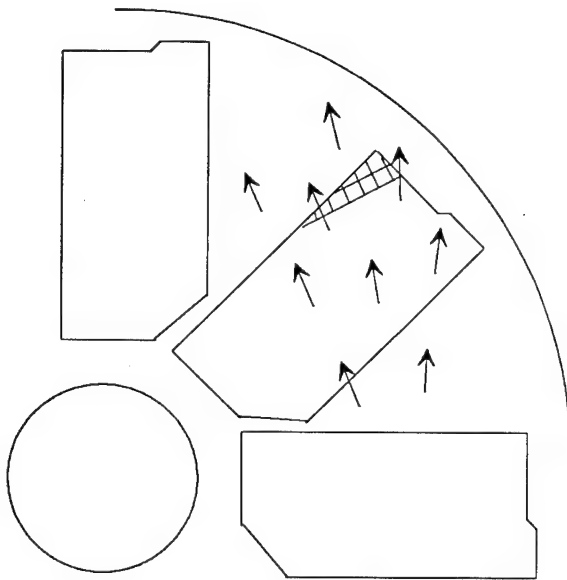


Figure 18 : Flow from Hole #2 at the Three O'Clock Vane, LSMR4

5.4. Revision Five

As described above, with the LSMR1 liner flow through hole #3 at the three o'clock vane appeared to intermittently sweep the area of the half past one vane upon which hard carbon was forming. The effect of enlarging this hole was investigated. This modification, designated Low Smoke Modification Revision Five (LSMR5), is distinguished from the standard Series III configuration as follows:

- Modifications as previously stated which produced LSMR1.
- Hole #3 at the three o'clock position - size increased from 0.125 inches to 0.202 inches.

As shown in Figure 19, titanium dioxide particles flowing from the modified hole behind the three o'clock vane swept the critical area entirely. The particles clung to the entire region of the half past one vane over which the fluid swept, indicating the flow was impinging on the surface of the vane.

The effect of increasing the diameter of hole #3 on titanium dioxide particles entering the liner through hole #2 at the three o'clock vane can be seen in Figure 20. There was a minor bulk movement of the flow outwards across the critical area on the downstream vane. Particles entering through hole #1 at the half past one vane was also investigated, but no noticeable changes in flow condition could be detected.

Analysis of all the evidence from the water model tests indicated that LSMR5 would be more effective than LSMR4 in energising the flow over the location of carbon formation. This was supported by results from limited 'hot' testing of the two modifications. On this basis, LSMR5 was selected for comprehensive experimental evaluation.

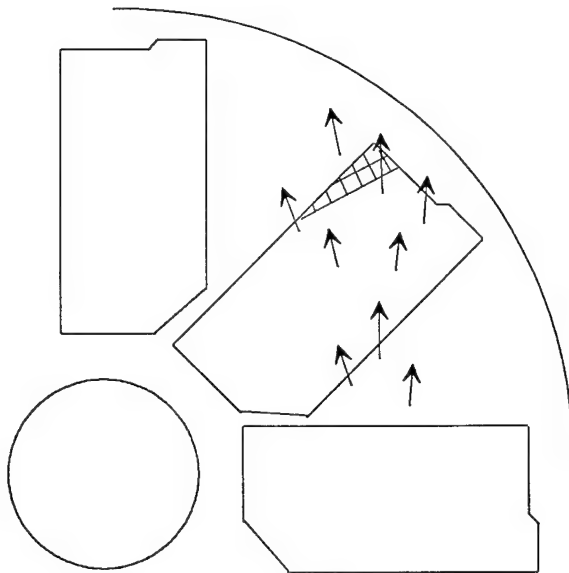


Figure 19 : Flow from Hole #3 at the Three O'Clock Vane, LSMR5

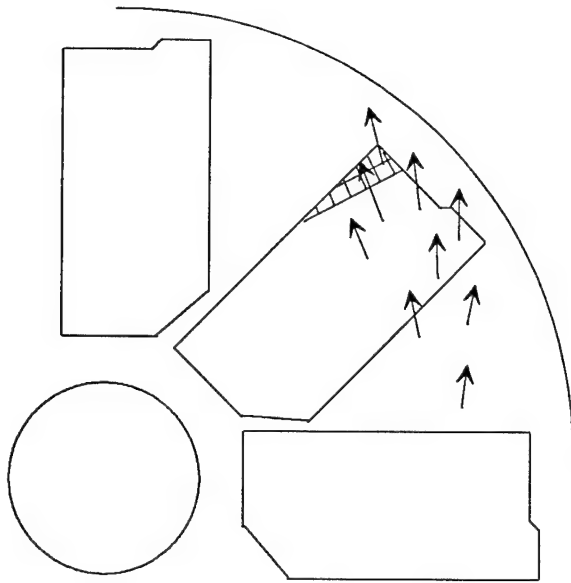


Figure 20 : Flow from Hole Number Two at the Three O'Clock Vane, LSMR5

6. Concluding Remarks

The water flow investigation achieved its objective of determining flow patterns within the primary section of the T56 combustor liner and defining revised configurations for the LSM which might eliminate hard carbon formation in the dome region of the liner. In summary, the investigation found that:

- The basic flow characteristics within the primary section of the liner were as outlined by Skidmore (Reference 2).
- The main toroid in the primary section of the liner had been shifted upstream as a consequence of the LSM, and had increased in size.
- Flow through the dummy igniters can influence the flow characteristics of the main toroid.
- The diameter of dome air inlet holes can influence significantly the flow in the region where hard carbon was known to be forming.
- Revisions to the original LSM configuration can be made by way of enlargement of some of the dome air holes which should eliminate its propensity to form hard carbon in the dome region of the liner.

The revision designated LSMR5 was selected for comprehensive investigation in the 'hot' T56 combustion rig, and ultimately for a full engine testing program. Successful conclusion of the program would lead to a certification succeeding the LSM combustor, with the designation RLSM.

8. Acknowledgments

The work of this report relied on the assistance, advice, and cooperation of the professional and technical staff at AMRL. In particular, I would like to acknowledge the contributions of the following;

- Mr. Frank Skidmore, the engineer leading the Task who provided direction and invaluable advice during the course of the investigations.
- Mr. Martin Fisher, for the speed and high standard of his technical support.
- Mr. Peter Radford, Foreman of the AMRL machine shop, who during times of extreme manpower shortages and high workloads, still managed to provide expertise at short notice.

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G.T. McCabe

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DOCUMENT CONTROL DATA

1a. AR NUMBER AR-007-138	1b. ESTABLISHMENT NUMBER DSTO-TR-0139	2. DOCUMENT DATE MARCH 1995	3. TASK NUMBER AIR 94/097
4. TITLE WATER MODEL TESTS ON THE ALLISON T56 SERIES III COMBUSTION SYSTEM		5. SECURITY CLASSIFICATION (PLACE APPROPRIATE CLASSIFICATION IN BOX(S) IE. SECRET (S), CONF. (C) RESTRICTED (R), LIMITED (L), UNCLASSIFIED (U)).	6. NO. PAGES 28
		<div style="display: flex; justify-content: space-around;"> <div style="border: 1px solid black; padding: 2px 10px;">U</div> <div style="border: 1px solid black; padding: 2px 10px;">U</div> <div style="border: 1px solid black; padding: 2px 10px;">U</div> </div> <div style="display: flex; justify-content: space-around; font-size: small;"> DOCUMENT TITLE ABSTRACT </div>	7. NO. REFS. 5
8. AUTHOR(S) G.T. McCABE		9. DOWNGRADING/DELIMITING INSTRUCTIONS Not applicable.	
10. CORPORATE AUTHOR AND ADDRESS AERONAUTICAL AND MARITIME RESEARCH LABORATORY AIRFRAMES AND ENGINES DIVISION PO BOX 4331 MELBOURNE VIC 3001 AUSTRALIA		11. OFFICE/POSITION RESPONSIBLE FOR: RAAF-DTA-LC SPONSOR _____ SECURITY _____ DOWNGRADING _____ APPROVAL _____ CAED	
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14. DESCRIPTORS Allison T56 engines Combustion chamber liners Erosion corrosion Erosion control			15. DISCAT SUBJECT CATEGORIES
16. ABSTRACT A modification was developed for the combustion system of the Allison T56 Series III turboprop engine which has resulted in an engine that has: <ul style="list-style-type: none"> • a lower smoke emission; • a lower specific fuel consumption; and • a combustor with potentially increased durability or life. 			

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16. ABSTRACT (CONT).

In-service testing of the combustor has proven all the above advantages, however, the formation of hard carbon in the combustor and its subsequent release has resulted in increased erosion in the turbine section of the engine. Further development was undertaken to remedy this problem without affecting the overall gains offered by the modification. This report covers part of this work and in particular details flow field investigations made using a water flow model of the combustor liner. A comprehensive understanding of the flow mechanisms within the standard liner, the Low Smoke Modification liner (LSM), and proposed revisions of the LSM liner has now been obtained. It is anticipated that modifications arising from the present investigation will reduce, if not completely eliminate, hard carbon formation in the Revised LSM (RLSM) form.

17. IMPRINT

AERONAUTICAL AND MARITIME RESEARCH LABORATORY, MELBOURNE

18. DOCUMENT SERIES AND NUMBER

DSTO Technical Report 0139

19. WA NUMBER

20232J

20. TYPE OF REPORT AND PERIOD COVERED

21. COMPUTER PROGRAMS USED

22. ESTABLISHMENT FILE REF.(S)

M1/9/66

23. ADDITIONAL INFORMATION (AS REQUIRED)